

Catalytic Combustor for Ultra-Low NOx Advanced Industrial Gas Turbines

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Microturbine & Industrial Gas Turbines
Peer Review Meeting
Fairfax, VA

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Clean Power Solutions for the 21st Century®



Presentation Outline

- ***Motivation***
- ***RCLTM Concept***
- ***Test Results:***
 - ***Performance***
 - ***Emission***
 - ***Durability***
- ***Summary***
- ***Commercialization***



Motivation

Develop a catalytic combustion technology

- *capable of high-firing-temperature operation*
- *with well-controlled catalyst temperatures, over a wide operating range*
- *tolerant to wide variations in inlet temperature and F/A ratio*
- *of compact size & low pressure loss (no preburner, relaxed mixing requirements)*
- *fuel flexibility operation.*

...that addresses the limitations of previous catalytic combustion technology.



Relevance to Overall Program Objectives

| Category | DOE Goals | RCL™ Goal |
|------------------|--|---|
| Emission | NO _x <5 Acceptable CO | NO _x <3, CO<10 50%-100%Load |
| Fuel Flexibility | Consideration for back up & alternate fuel | Nat. gas, Low Btu, Gasoline, Diesel vaporized |
| Durability | At least 8000 hrs | 12000 hrs w/ 8000 hrs market entry |

Milestones

- **Full-scale ultra-low NOx demonstration**
- **Fuel flexibility demonstration**
- **Complete 1000 hours durability**

Targeted Engine Application

- **Solar Taurus T70**



Solar Turbines Inc. Team:

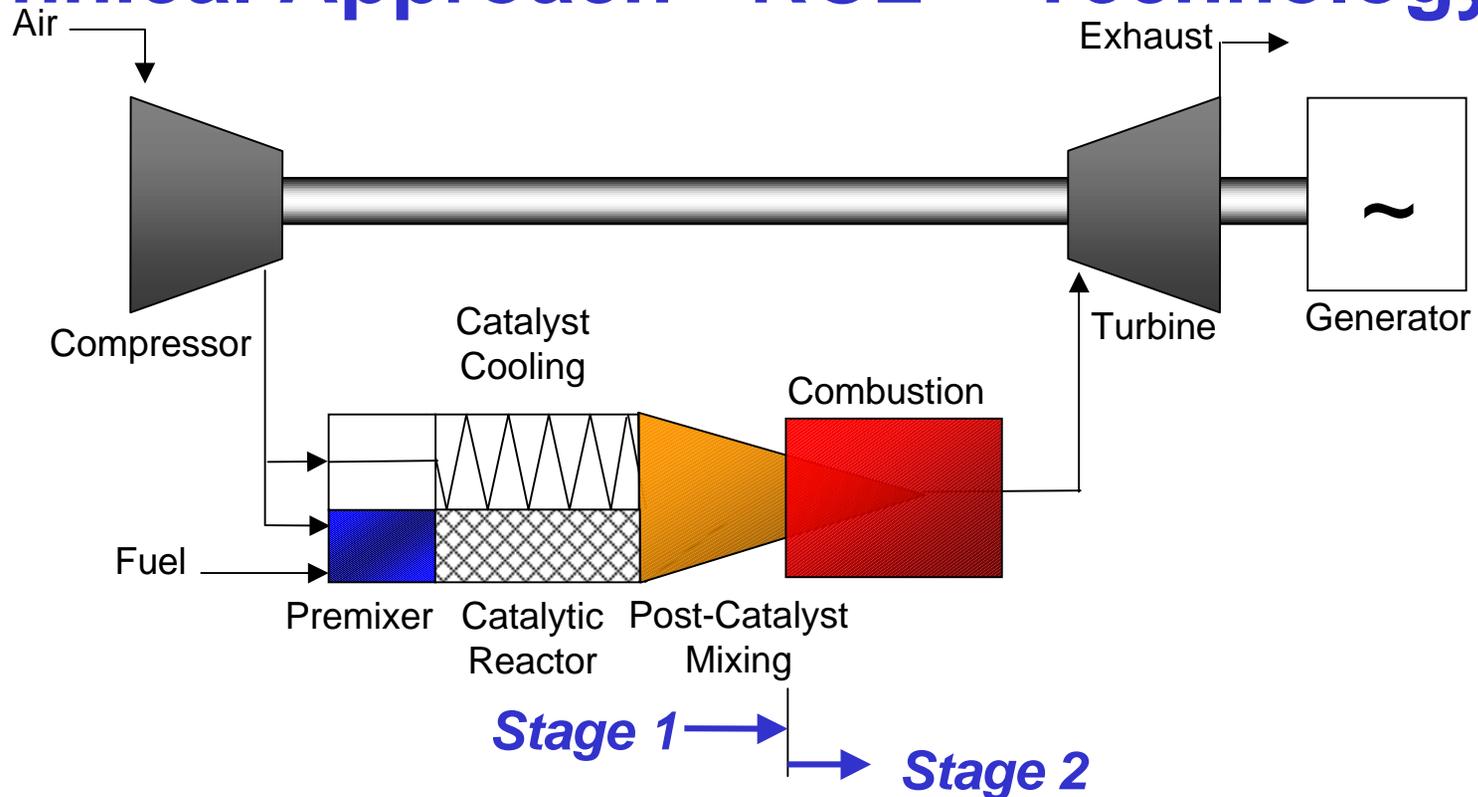
Dr. Ken Smith, Dr. Vivek Khanna

DOE Contract Monitor:

Mr. Steve Waslo



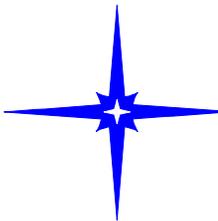
Technical Approach - RCL™ Technology



- **Rich- Catalytic / Lean-burn (RCL™) system:**

Stage 1. Fuel-rich catalytic partial oxidation

Stage 2. Fuel-lean gas phase premixed combustion



RCL™ System Scalability



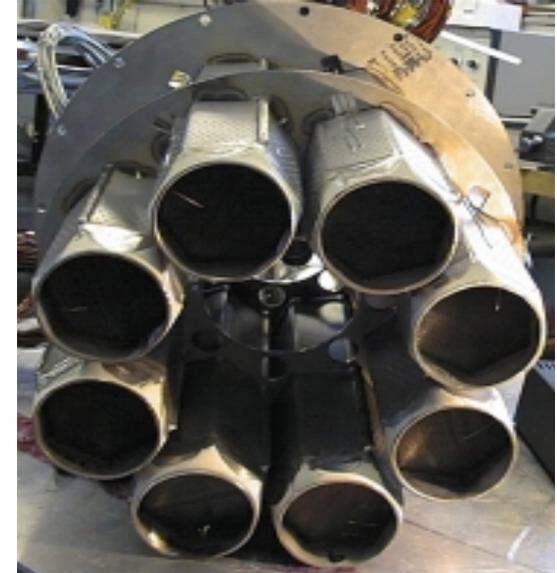
**Subscale
Reactor**

MW = 0.03 - 0.12



Module

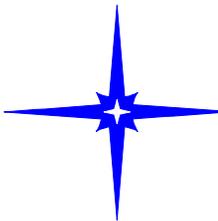
MW = 0.6 - 1.7



Combustor

MW \cong 10

- *RCL™ system is scalable for ease of implementation*
- *RCL™ system is readily retrofittable for different applications*

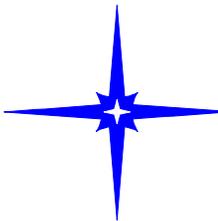


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Full-Scale RCL™ System Module

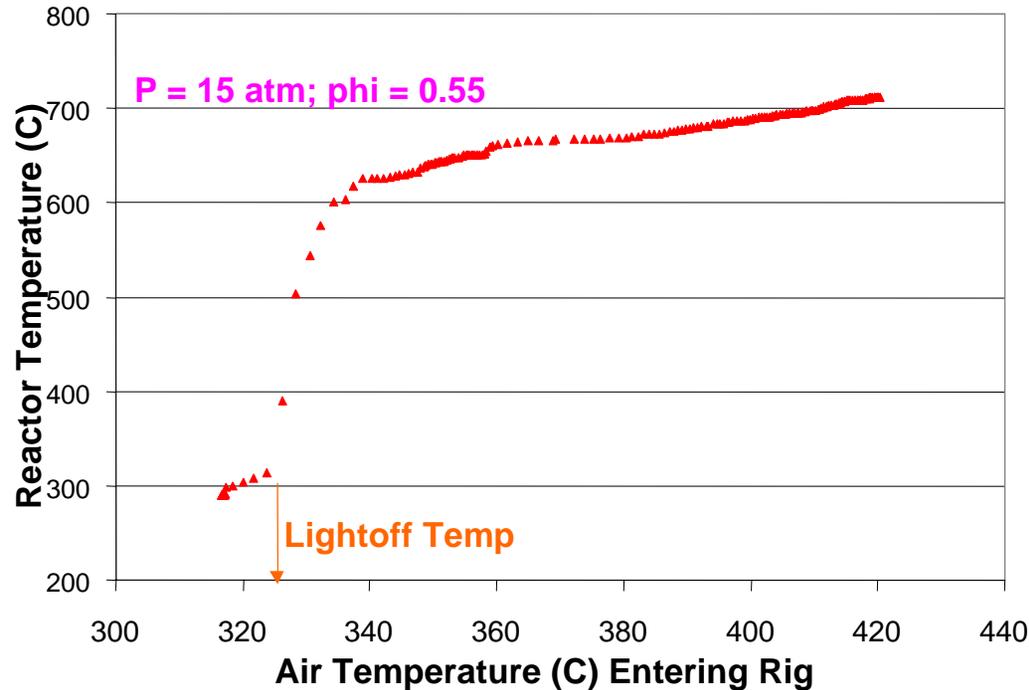


- ***Compact system with no pre-burner & integrated premixer.***
- ***Modular hardware fabricated for development purposes.***

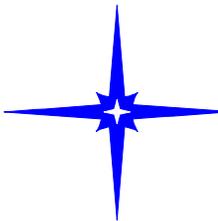


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No Preburner Required

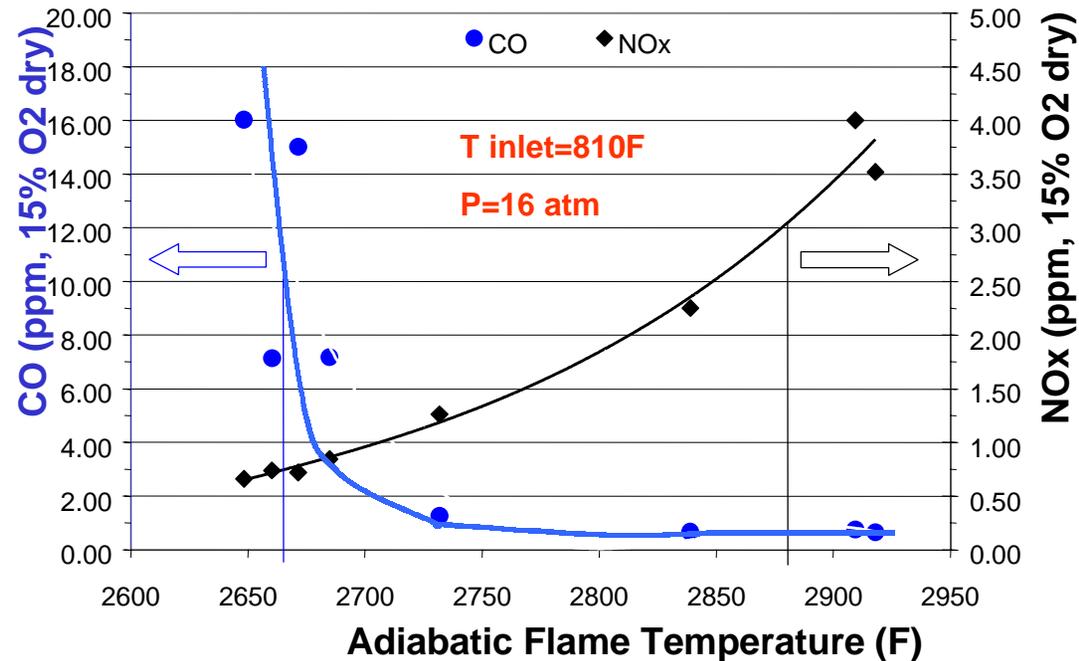


- ***Reactor design and catalyst formulation provides low lightoff.***
- ***Catalyst lightoff 300-350 C / 570-670F (15 atm)***
- ***No pre-burner required: Cost, space, durability & NO_x benefit***

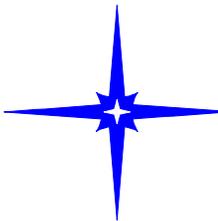


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RCL™ System Performance

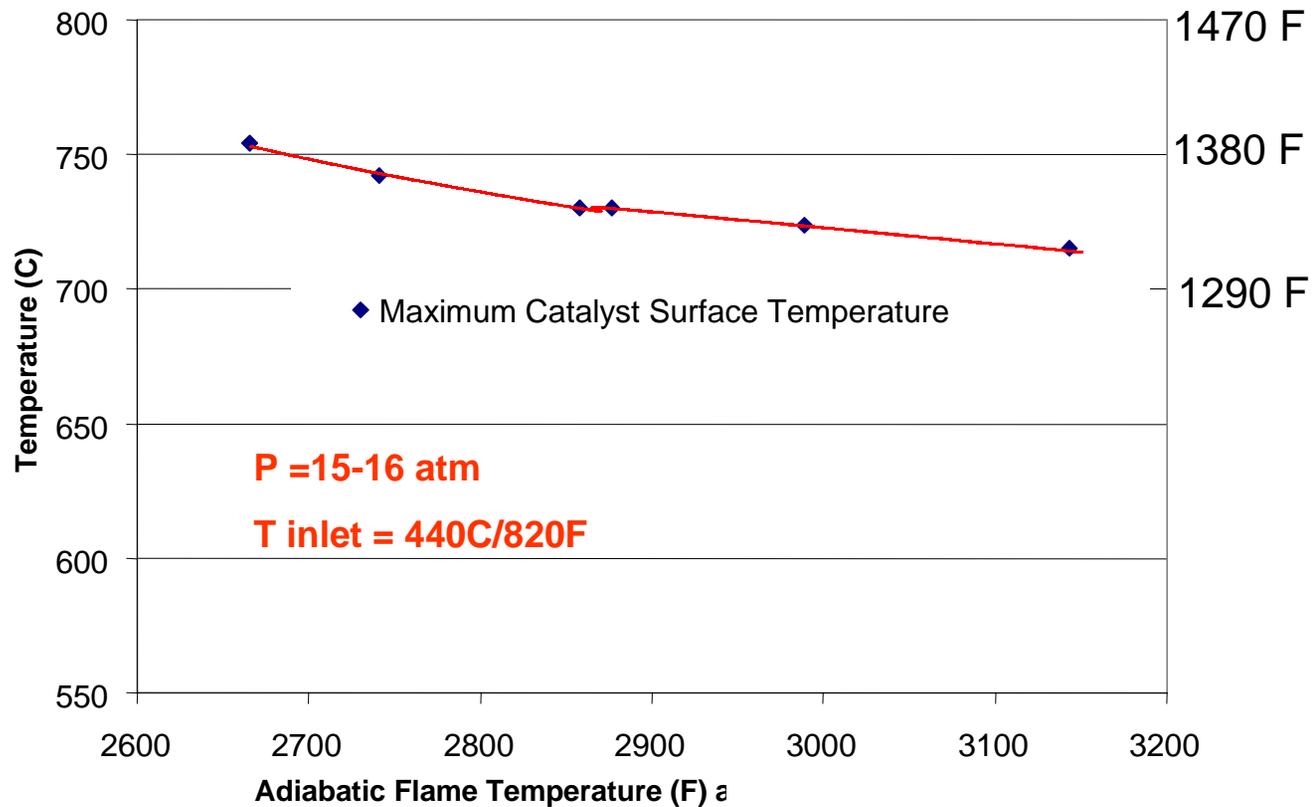


- **Low emission NOx<3ppm, CO<10ppm with large turndown (200F).**
- **Capable of high firing temperature operation.**
- **Pressure drop 4 %**
- **Saturn Engine test targeted April 2002.**

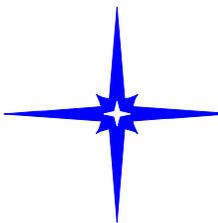


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Moderate Reactor Temperatures

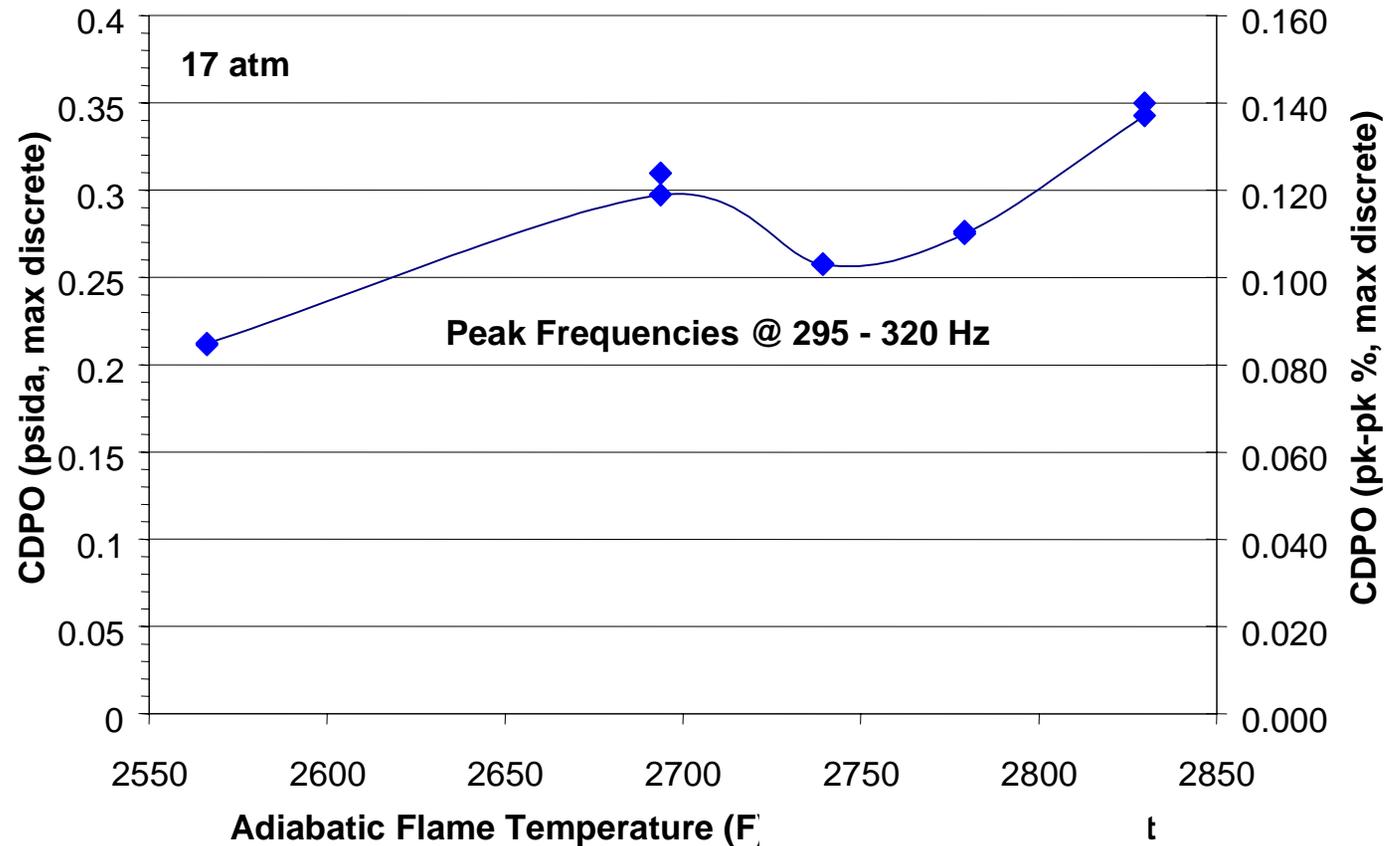


- ***Catalyst surface at moderate material temperature (durability)***
- ***Catalyst temperature insensitive to firing temperature***
- ***Catalyst output (gas temp. out) insensitive to operating condition***

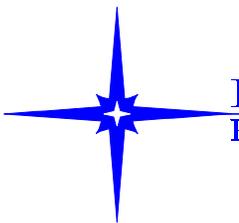


Quiet Operation during Module Tests

Combustion-Driven Pressure Oscillations (CDPO)

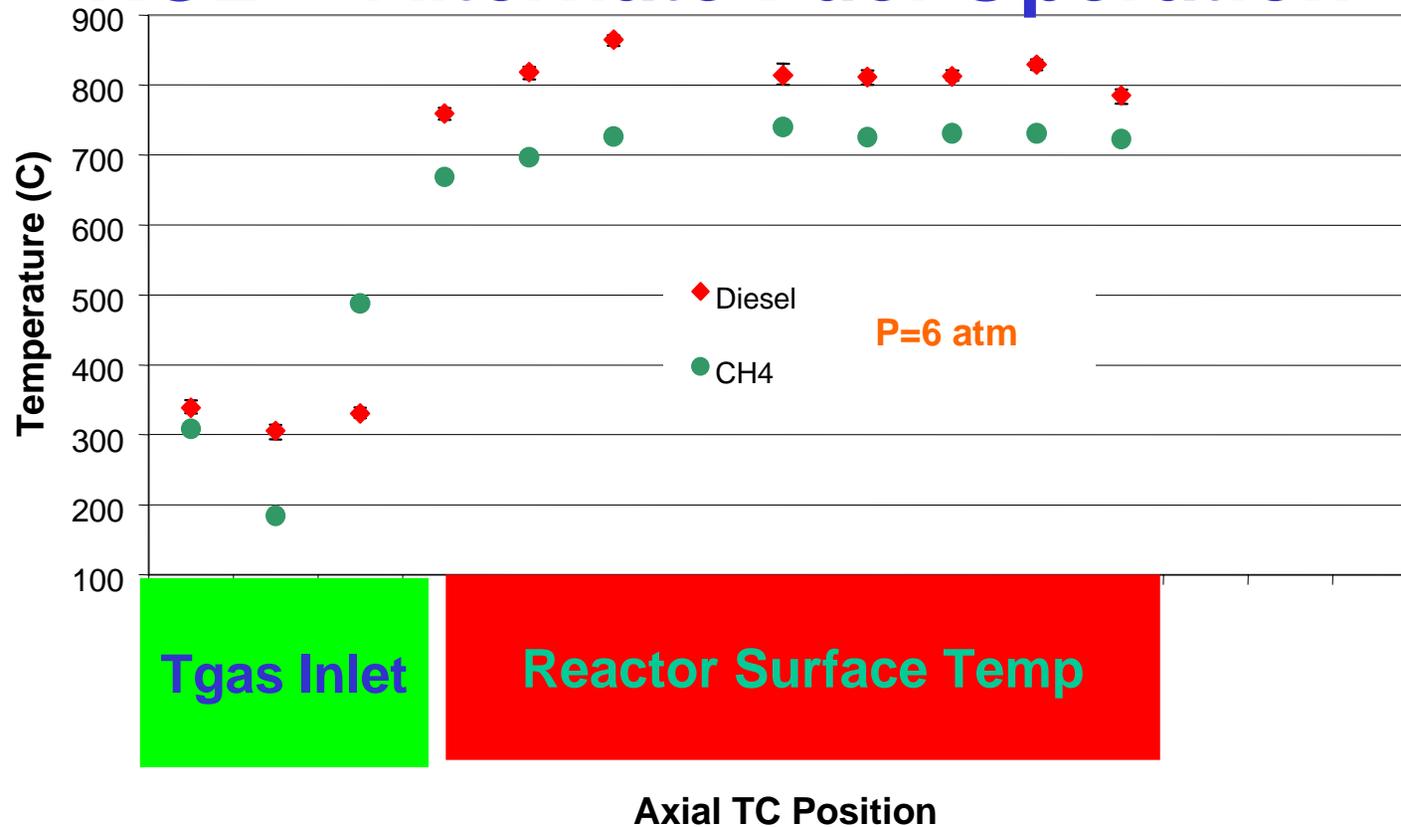


- ***Extremely quiet operation achieved, over wide operating range.***
- ***Low Dynamics < 0.3 psida at baseload.***



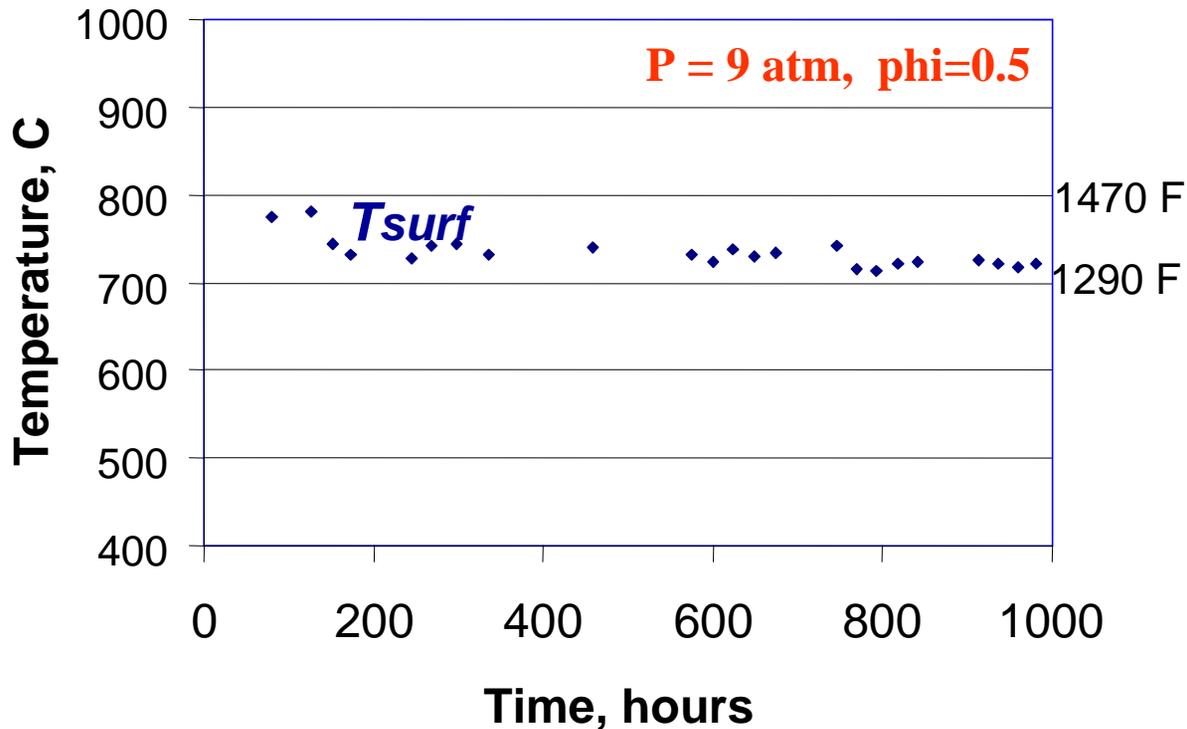
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RCL™ Alternate Fuel Operation

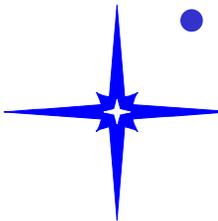


- **Same reactor successfully tested for different H/C fuels:
Natural gas, gasoline, Land fill gas, Diesel fuel DF-2 (prevaporized)**

RCL™ Reactor Durability

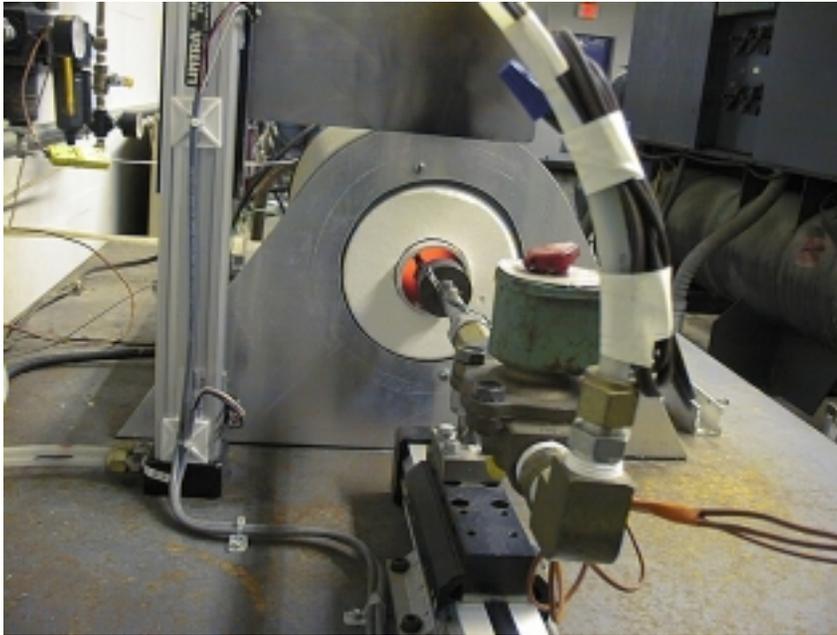


- **1000 hour durability test successfully completed.**
- **No measurable performance degradation - moderate temp, fuel-rich environment over catalyst .**
- **Initiating 2000 hours durability test.**



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RCL™ Cyclic Durability Testing



Thermal Cycle Tester -

cycled from furnace to quenched air blast cooling at 200-300C/sec

- ***8000 hours durability prediction based on cyclic testing of substrate and washcoat under stress conditions:***
 - ***>600 thermal cycles simulating engine trips at 200-300°C/sec with no washcoat failures***
- ***1000 hours in wet air @ 100°C above design point with negligible substrate oxidation***



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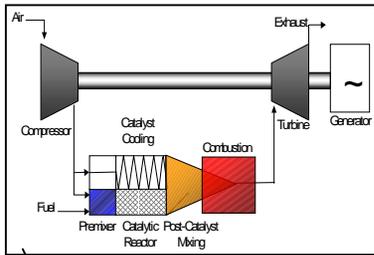
Accomplishments

| Category | DOE Goals | RCL™ Performance |
|-------------------------|--|---|
| Performance & Emissions | NO _x <5 Acceptable CO | NO _x =0.7-2.3, CO=0.7-7.2ppm for T _{adb} =2660-2840F 50%-100% Load P=10-16atm, T _{in} =820F/440C dp =4%, T lightoff=565F/295C Dynamics<0.4psida |
| Fuel Flexibility | Consideration for back up & alternate fuel | Operated same reactor on Nat. gas, Low Btu, Gasoline, Diesel No. 2, (pre-vaporized) |
| Durability | >8000 hrs | Completed 1000 hrs durability. Completed >600 trip cycles. Low reactor surface temperature. |

Summary

- ***Robust operation at high pressure with wide range of fuel flow rates (high firing - temperature capability)***
- ***Low NO_x and CO emissions***
- ***Wide turndown achieved: Ultra lean to high firing temperature***
- ***Low overall combustion acoustic operation***
- ***No pre-burner required***
- ***Compact design, radially and axially to fit into existing envelope***
- ***Moderate reactor surface temperatures to assure long term durability***

RCL™ Commercialization



RCL™ Patented Concept



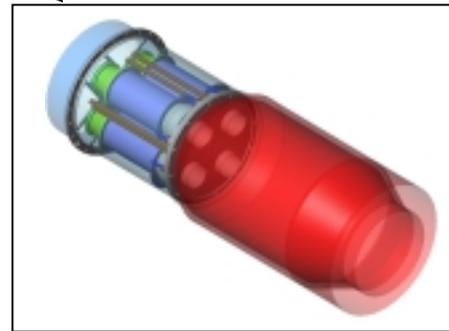
Component Dev. (9 atm)



Scale Up & Sys Integration (16 atm)



Engine & Field Testing (16 atm)



Transient Operation (6 atm)

- *Industrial Engine*

- *Micro-turbine*

- *Utility Engine*

Acknowledgements

- **DOE/DER-** Funding support.
- **Mr. Steve Waslo -**
 - Encouragement on RCL™ development
- **Solar Turbines:** High Pressure air time.
- **Dr. Ken Smith:** Technical Support
- **Dr. Vivek Khanna:** Technical Support

